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MINING AND ENGINEERING METHODS AND COSTS OF THE HANOVER BESSEMER IRON AND COPPER CO., FIERRO, NEW MEXICO

BY

LLOYD M. KNIFFIN

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MINING AND ENGINEERING METHODS AND COSTS OF THE HANOVER BESSEMER IRON & COPPER CO., FIERRO, N. M.[1]

By Lloyd M. Kniffin[2]

INTRODUCTION

This paper is one of a series being prepared by the United States Bureau of Mines on mining methods, practices, and costs in the various mining districts of the United States. It describes the mine of the Hanover Bessemer Iron & Copper Co. at Fierro, Grant County, N. M., which is the only operating iron mine in the southwestern part of the United States. This mine is in a district noted for the great variety of ores that it produces. Within a small area, as shown in Figure 1, there are noteworthy deposits of nearly all the common metals.

The ore occurs in lenticular masses dipping at about 50°. An underhand stoping method has been developed that requires but a very small amount of handling of ore. As the ore is very irregular in iron content and also in the distribution of the impurities--chiefly sulphur, silica, and magnesia--a method has to be used that will permit selective mining and will also allow ore and waste to be taken out separately as conditions change. A magnetic cobbing plant raises the grade of the ore shipped about 10 per cent.

Nearly all of the iron ore is shipped to Pueblo, Colo., a distance of 694 miles, where it is smelted by the Colorado Fuel & Iron Co. The mine is not a large producer, as the long distance from blast furnaces limits its output. In recent years the annual shipments have amounted to about 200,000 tons. The property is noteworthy chiefly on account of this long transportation by rail and the economical methods that have been developed to make the operation profitable. About 175 men are employed.

ACKNOWLEDGMENTS

The author acknowledges the assistance of Frank B. Harris, formerly mining engineer, Hanover Bessemer Iron & Copper Co., and C. H. Johnson, assistant mining engineer, U. S. Bureau of Mines, Tucson, Ariz.

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1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6361."

2 - One of the consulting engineers, U. S. Bureau of Mines, and manager, Hanover Bessemer Iron & Copper Co.

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HISTORY

It is probable that exploration for copper was carried on in the district several hundred years ago. Relics of Spanish operations have been found near the ancient adobe furnaces and slag dumps.

The large outcrops of magnetite attracted attention for many years, but the lack of transportation made them of no economic value. Soon after the railroad was brought to Silver City, some "float" ore was shipped to Pueblo, that had been hauled from Fierro by ox teams on the return trip after bringing supplies to Fort Bayard.

In 1888, a water-jacketed copper smelter was built at the Anson S mine, but this was operated only one year.

The Santa Fe Railroad was extended by stages; in 1891 it reached Hanover, and the shipment of iron ore for fluxing purposes to the copper smelters at Socorro and El Paso was started.

The Hanover Bessemer Iron Ore Association was organized in 1899, at which time the railroad was built to Fierro. A lease was arranged with the Colorado Fuel & Iron Co., and shipments to Pueblo started. In 1914, the Hanover Bessemer Iron & Copper Co. was incorporated, and a contract was made for the sale of iron ore. A fine-grinding wet-concentration mill was built in 1916. A controlling interest was acquired by the United States Smelting Refining & Mining Co. in 1919.

GEOLOGY

The United States Geological Survey has described the general features of the district.[3] Many difficult problems are presented, and much additional time has been spent on them.

A section of the formation at Fierro is shown in Figure 2. An intrusive betholith of granodiorite forced its way through the sedimentary rocks and raised them in a dome. The fractured surface was eroded more easily than the surrounding rock, and the capping was removed and a valley worn away in the granodiorite. The metamorphosed portion of the sedimentaries resisted erosion and now stands out in ridges 300 to 400 feet higher than the creek level. The exposed portion of the granodiorite is about one-half mile east and west and 1 1/2 miles north and south.

The granodiroite is apparently part of the parent magma of the district, its deep-seated nature being shown by the coarseness of the mineral crystals. While the mass was still heated the metallic elements were carried outward, seeking favorable conditions for deposition. Apparently iron was most abundant and deposited at the highest temperature, close to the contact of the igneous mass and the sedimentary rocks. The fractured limestones afforded the desired conditions, and replacement took place in varying degrees. In some places the

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3- Geologic Atlas, Silver City Folio No. 199, Sidney Paige.

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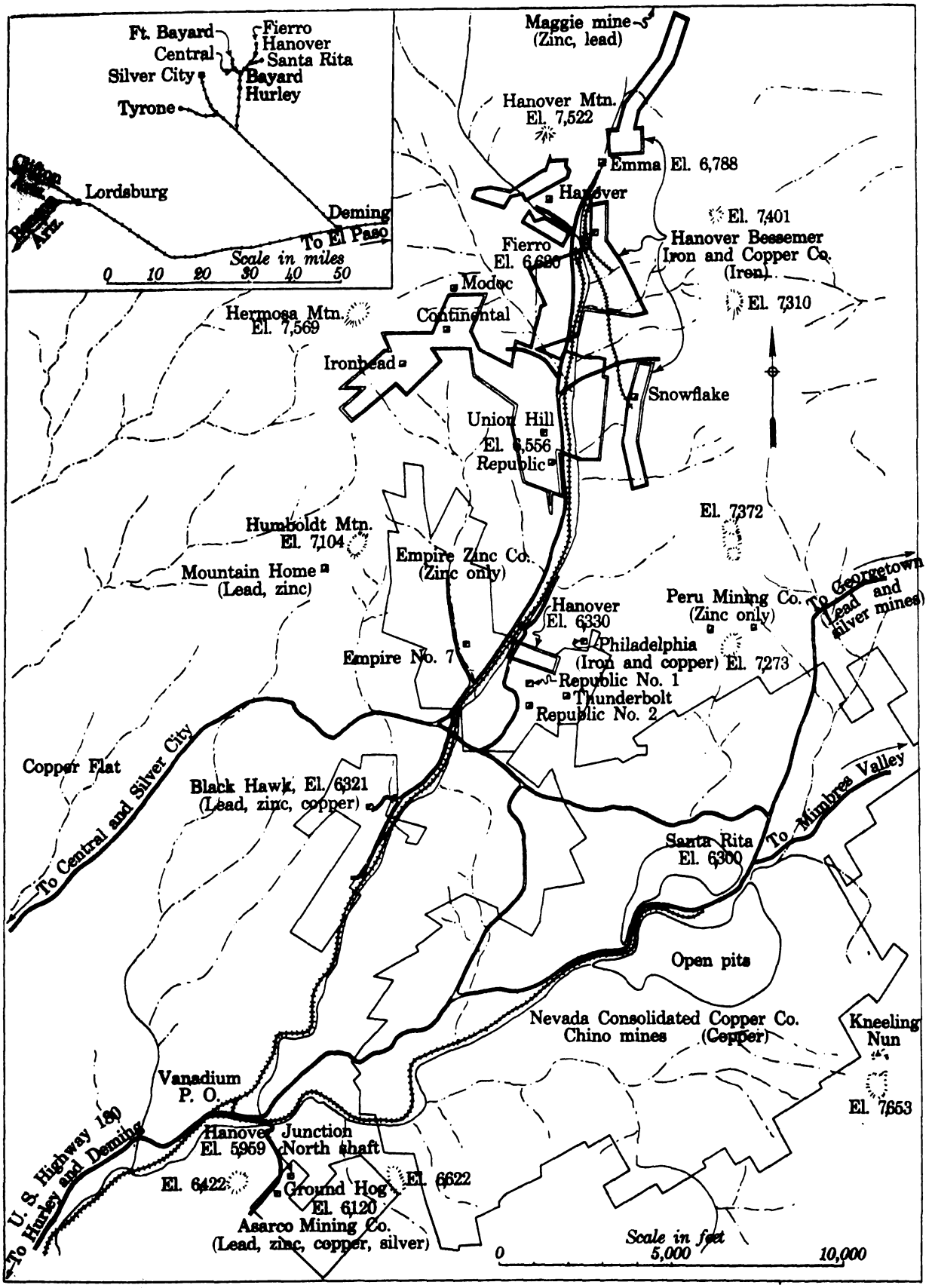

Figure 1. – Portion of central mining district, New Mexico

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NOTE: Bliss sandstone and pre-Cambrian granite (schist) outcrop in several places around the border of the granodiorite

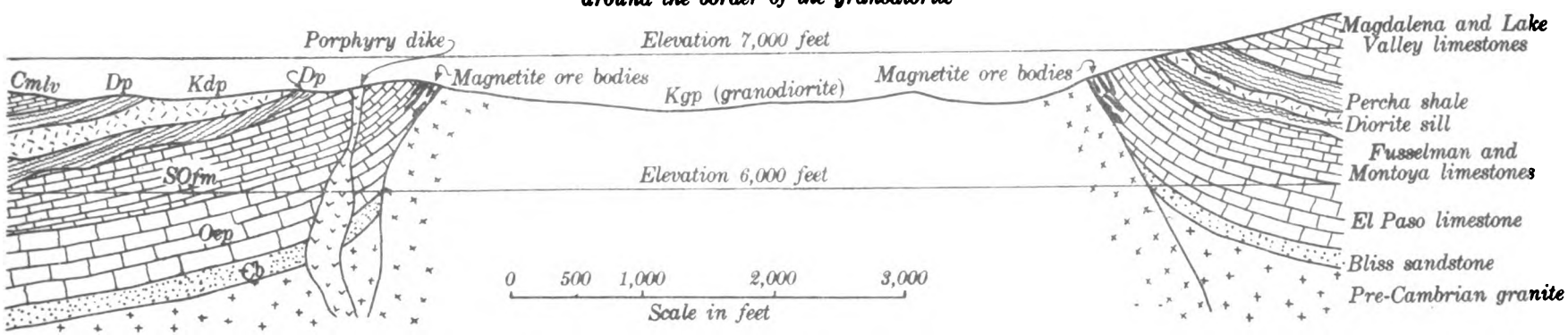

Figure 2. – Geologic section

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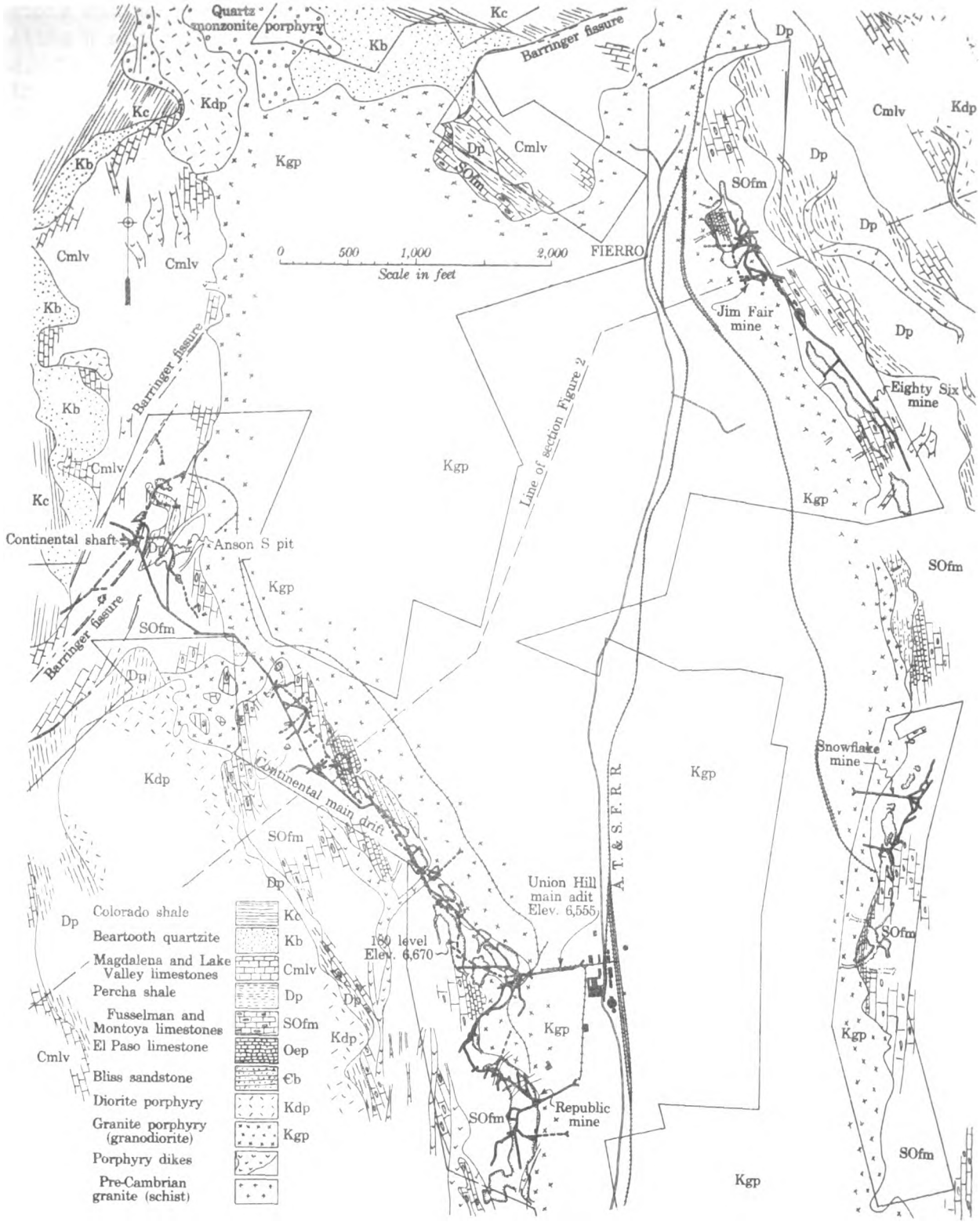

Figure 3. — Principal mine workings and surface geology

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limestone was nearly pure and was almost completely replaced. Some bodies of magnetite near to the chemical composition Fe_3O_4 (Fe = 73.36 per cent) have been mined. This class of ore is always surrounded by crystaline limestone of great purity. In other places, beds high in silica were partly replaced, and ore low in iron resulted.

The larger part of the ore is a replacement of the El Paso Limestone. Dr. A. C. Spencer of the U. S. Geological Survey was able to identify one of the ore beds, which has a banded arrangement made up of alternate layers of serpentine and magnetite, as being a replacement of a lower member of the El Paso limestone and another, a spotted ore, which contains nodules of serpentine in magnetite, as a replacement of a bed at the upper part of the El Paso limestone. This bed, when unaltered, contains nodules of chert. Dr. Spencer has also noted that some of the ores were deposited in the Bliss sandstone at the very base of the sedimentary strata, next to the pre-Cambrian gneiss. This accounts for the high silica percentage of such ores. From these relations we can now tell where nearly all of the replaced beds occurred in the geological column. This information has been a great help in mining operations, particularly in directing the development of ore low in silica.

Some copper sulphide was deposited with the magnetite as the minerals chalcopyrite and chalmersite[4]. This iron ore when unaltered contains about 0.60 per cent of copper. In addition, the copper sulphide minerals moved away from the contact zone to places where lower temperature conditions prevailed and where little magnetite was deposited. In the neighboring mines at Santa Rita the copper minerals are disseminated through large masses of Colorado shale and invading igneous rocks.

The effect of temperature on the deposition of the ores has brought about a zonal arrangement of the ores that is a marked characteristic of this district. The order of these zones is as follows, starting from granodiorite core:

1. Magnetite with small amounts of sulphide copper
2. Chalcopyrite low in magnetite
3. Sphalerite with some magnetite
4. Sphalerite with low lead
5. Sphalerite and galena
6. Galena and silver

Nearly all of the mines of the district are found in these zones as will be seen by reference to Figure 1.

Barringer Fissure

As will be noted from Figure 3, a major preintrusive fault zone bears northeast and southwest through the sedimentaries. The throw of this fault is estimated to be approximately 1,200 feet vertically and 800 to 900 feet

4 - Schwartz, G. M., Chalmersite at Fierro, New Mexico with a Note on Its Occurence at Parry Sound, Ontario: Econ. Geol., vol. 18, No. 3, April-May, 1923.

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horizontally. The movement was spread over a wide area and left a favorable zone for the deposition of ore. In general, the ore along this fissure, as compared with the contact ore, has about half the percentage of magnetite, much more pyrite, and about three times the quantity of copper. As the distance from the granodiorite increases, zinc occurs in increasing percentages.

The outcrops along the Barringer fissure have been oxidized and leached, and lenses of brown iron ore, locally called hematite, have been left behind. The copper has been concentrated in zones of secondary enrichment and is found as native copper and as cuprite and chalcocite.

Ore Bodies

The magnetite ore bodies occur in the first zone. They are very irregular in size but run more or less parallel to the granodiorite contact and are usually lenticular. In a few cases a thickness of 200 feet is attained, but the average is about 40 feet. In many instances alternate beds have been replaced, leaving beds of altered rock and low-grade iron between. Oftentimes four parallel beds are found. When these merge a wide zone of ore is found. The mining of such parallel deposits requires great care, especially in keeping the pillars in alignment.

The dip of the ore bodies is usually between 50° and 60° away from the granodiorite, although, in a few cases, a reverse dip occurs. The dip appears to be flattening with depth.

A number of dikes of porphyritic texture emanated from the granodiorite and cut across the ore. Usually these dikes extend but a short distance into the limestone beyond the ore.

There have been many minor faults cutting the ore bodies, and slickensides are much in evidence. The pressure has evidently been very great, but the displacement is not usually large. In general, the direction of the faulting and of the dikes is northeast and southwest. These dikes and minor faults have not materially influenced the ore bodies, although their presence makes many changes in mining necessary.

In the replacement of the limestone beds, a considerable part of the magnesia remained behind. The average partial analysis of the concentrate shipments is as follows:

	Per cent
Fe	51.00
P	.058
SiO_2	7.28
Mn	.72
Al_2O_3	1.42
CaO	1.41
MgO	13.38
Cu	.37
S	.38

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The ore from which the concentrates were made came from mining operations near the surface. Some of the copper that was originally present had been leached from this ore. Some secondary minerals, such as serpentine, containing magnesia, were also formed. The ratio of magnesia to the other impurities introduces difficulties in smelting.

EXPLORATION

Diamond Drilling

Diamond drilling is done on company account. The work is done by a drill runner and a helper on each shift; they are supervised by the diamond setter. This system has proved more economical than contract work.

Holes to be drilled are planned by the mining and engineering departments, and a budget is prepared covering the year's operation. It has been found that diamond drilling is especially useful in directing development drifts and in avoiding unnecessary work. The holes range from 200 to 500 feet in depth.

Experience has taught that a fan of diamond-drill holes from one setup gives much more reliable data than single holes. Very often, single-hole data are not to be trusted and are often disappointing when followed by development. The average cost of diamond drilling per foot of hole drilled is as follows:

Cost per foot of diamond drilling

	Labor	Supplies	Repairs	Compressed air	Total
Drilling	$0.562	$0.219	$0.051	$0.135	$0.967
Setting bits	.064	.017	---	---	.081
Carbon	---	.207	---	---	.207
Moving	.158	.028	---	---	.186
Total	$0.784	$0.471	$0.051	$0.135	$1.441

Prospect Drilling with Rock Drills

Jackhammer drills are used constantly with steel up to 20 feet long for obtaining information in advance of headings. The information secured from these is especially valuable in the stopes, but holes are also drilled at the surface and in raises and drifts. Many valuable lenses of ore have been found in this manner, that would otherwise have been missed.

From these 20-foot holes the grade of ore is determined by assays of drill cuttings. The thickness of dikes and horses is ascertained in many instances and the approximate dips of bodies are determined. This class of prospecting is extensively used, and very important information is thus gained at very reasonable cost. Its limitation is the length of drill rod that can be handled at the sur-

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face or underground.

Deep-hole drilling by the use of mounted Layner machines with sectional drill steel was used for pospecting for a time. These holes proved more expensive than diamond drilling, and the information was not as reliable. The method is now seldom used. The cost of this work per foot drilled for 836 feet was as follows:

Cost per foot of deep hole drilling

	Labor	Supplies	Repairs	Air	Total
Drilling	$0.877	$0.609	$0.524	$0.449	$2.459
Sharpening	.161	---	---	.008	.169
Moving	.179	.014	---	---	.193
Total	$1.217	$0.623	$0.524	$0.457	$2.821

The couplings and other equipment were carefully made, and the high cost is attributed to the hardness of the rock and ore. The average advance per shift was only 8.84 feet.

Magnetic Surveying

A magnetic survey has recently been made of the surface of all of the property that might contain ore bodies. For this work two magnetometers were used that were made by the Askania Corporation of Germany. These instruments are of the vertical field type, which show the maximum negative or positive variation directly above the cause of the disturbance. Only the vertical component of the magnetic field was measured. Two instruments were used, one with a high scale value which gave readings that could be measured over large variations. The other more sensitive magnetometer was used for areas where small variations were expected.

In starting this work the surface was laid out in a checkerboard with square 100 feet long on each side. As nearly as possible the lines were arranged at right angles to the expected strike of the ore bodies. Magnetic readings were made at each intersection. In some cases, intermediate readings were made.

The readings were plotted on maps drawn to a scale of 100 feet to the inch. On these maps was also placed all of the available geological information, because interpretation of the magnetic readings requires careful coordination of geological information. The indications were divided into four classes, according to the strength and persistency of the readings. The susceptibility of magnetite is several times greater than that of any of the other mineral found in quantity in this district; it was therefore safe to assume that the highest readings indicated magnetite bodies. Some of these readings ran up to over 40,000 gammas, as compared with normal readings away from the field, of 3,500 gammas. Inter-

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mediate readings which ran up to 20,000 gammas probably indicated hematite and sulphide bodies and were classed as "mineral indications". Indications and "traces" were two subdivisions of weak readings on sulphide or oxide bodies.

The "magnetite indications" are now being tested by diamond drilling. It is too early to appraise properly the results obtained by the magnetic surveying. It appears, however, that the readings do not show to very great depth. The bodies that are indicated are probably close to the surface. It is desirable to check the results obtained by magnetic surveying by some form of electrical surveying. A combination of the two methods would be very useful as a means of obtaining preliminary information.

The cost of this work was as follows:

Cost per acre.....1,148 acres.....	$ 3.30
Cost per station...7,418 stations.....	.51

SAMPLING AND ESTIMATION

The accurate control of so many chemical elements--iron, sulphur, silica, phosphorus, copper, and manganese--requires careful sampling methods. The principle employed is to take the samples at points where a large quantity of the material is broken to as fine a size as possible.

Development samples are taken as the material is loaded into the cars. It is found that blasting in drifts and raises breaks the ore quite fine and gives a quite thorough mixture. This sample, representing the full cross section of the heading, is more valuable than the small area of a channel sample. When the face is made up of two or more classes of material it is necessary to sample each separately by channeling. The ore in most cases is very hard, and jack-hammer drills are found to be useful in cutting these channels. A sampler is employed in the mine on each shift to see that the samples are properly taken.

Stope samples are in general taken from a conveyor belt in the crusher plant after the ore has been broken to minus 5-inch size. Special samples are taken in the stopes as required. These are either chipped or obtained by drilling into the walls.

Finished products are sampled by automatic equipment in the concentrating plant.

Development samples are assayed and plotted on tracings of the mine plans and vertical sections, the latter being usually at 100-foot intervals though sometimes at 50-foot intervals.

Weighted assays are used in obtaining final grade in ore estimates. These estimates of ore tonnage are prepared by taking the areas from the sections with a planimeter. From these areas the volume is calculated by the use of the prismoidal formula. Ore of high iron content is taken at 9 cubic feet to the ton, and lower grade material at 10 cubic feet per ton.

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METHODS OF DEVELOPMENT AND MINING

Drifting

As will be noted by reference to Figure 3, the Continental main adit starts in the granodiorite on the west side of Hanover Creek and encounters the contact at 400 feet from the portal. It continues under the contact ore body to its junction with the Barringer fissure already described.

All haulageways are 8 feet wide by 7 feet high. In driving these drifts the labor is paid on a contract basis per foot of advance. The supplies are provided on company account. A center cut round is used in drilling. The number of holes is varied to suit the hardness of the ground. Average drifting costs are as follows per foot of advance.

Cost of drifting per foot of advance

	Labor	Supplies	Compressed air	Total
Drilling	$2.72	$1.32	$1.09	$5.132
Explosives[1]	—	2.05	--	2.047
Mucking	1.69	.18	--	1.868
Timbering	.98	.83	--	1.816
Piping	.11	--	--	.109
Tracks	.63	.44	--	1.071
Total	6.13	4.82	1.09	12.043

[1] 50 per cent strength gelatin dynamite.

Standard timber sets of New Mexico Douglas fir, treated with creosote, are used where necessary. Figure 4 shows the method of timbering on curves. Thirty-five-pound standard rails are used throughout the haulage level at a track gage of 36 inches spiked to 5-inch by 5-inch by 5-foot timber ties at 24-inch centers. Ties also are treated with creosote before being used. Track grades are carried uniformly 0.5 per cent in favor of the loaded trains. All curves in the main drift are made upon a 100-foot radius, and the crosscuts are driven from drift on curves of 54-foot radius. This makes a satisfactory track and drift layout for heavy trains and constant use, with a minimum of repairs and haulage troubles.

A useful method of obtaining a smooth curve has been developed by the engineering department. After the point of curve is determined, a 6 by 6 timber is fastened horizontally in the roof. On the bottom side, spads are driven at uniform intervals so that they can be used successively to give the center for each 5-foot round. After the spads are placed the miner can put in the curve without additional engineering assistance.

Forced ventilation is necessary only in long dead-end headings. This is supplied as required through vent tube by motor-driven fans. A single-stage fan can carry sufficient air for a distance of 1,000 feet to ventilate the face.

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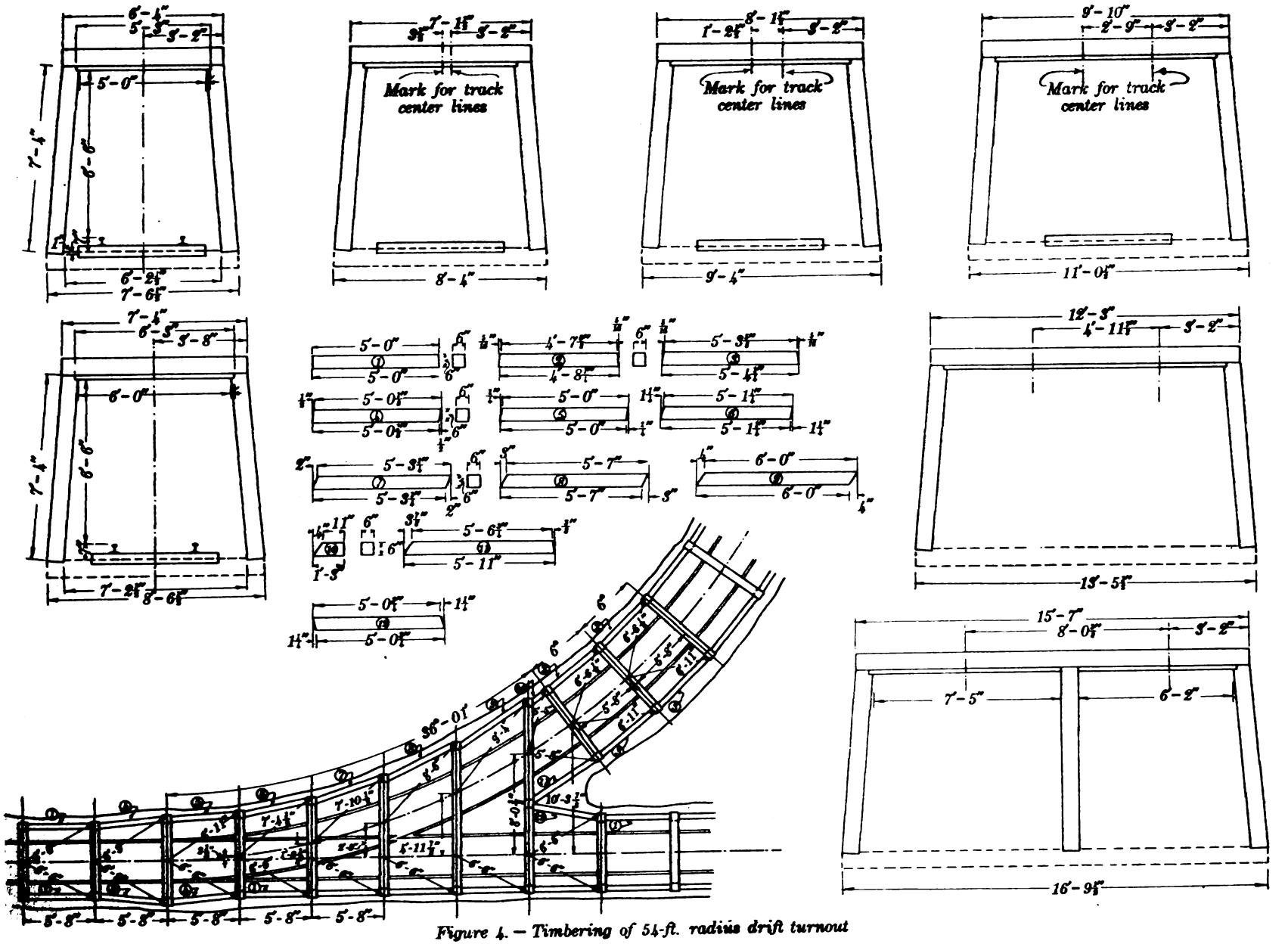

Figure 4. — Timbering of 54-ft. radius drift turnout

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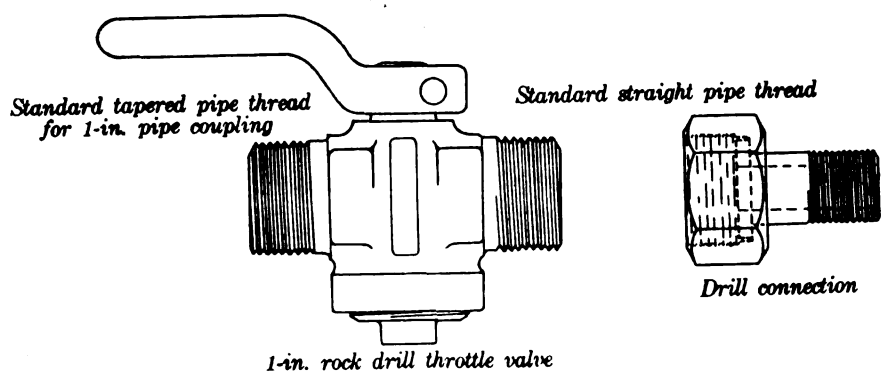

Standard tapered pipe thread for 1-in. pipe coupling
Standard straight pipe thread
Drill connection
1-in. rock drill throttle valve

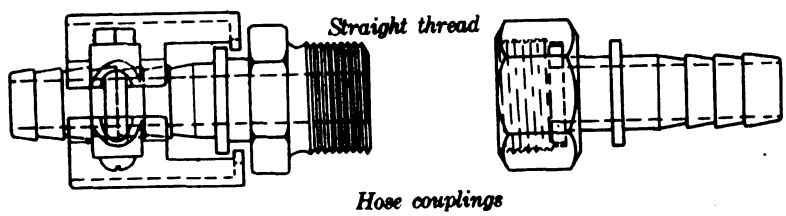
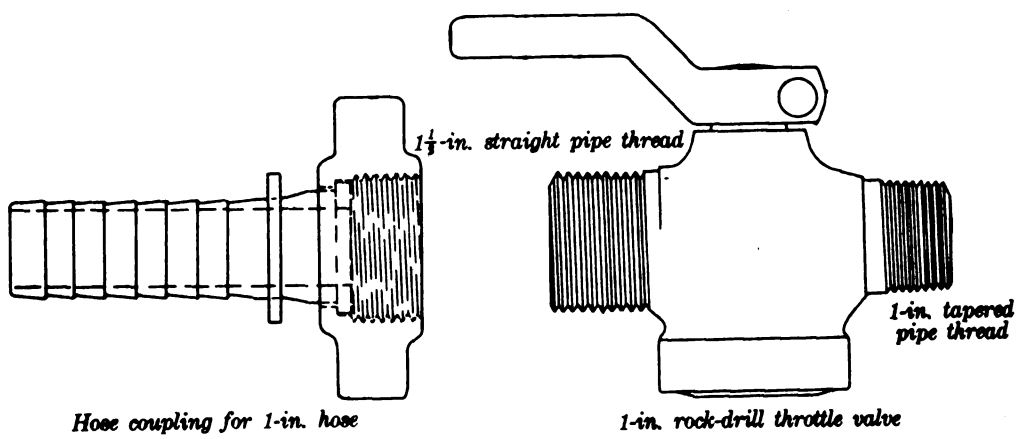


Figure 5a. – Valve and hose fittings for stopers and drills, using $\frac{3}{4}$-in. air hose



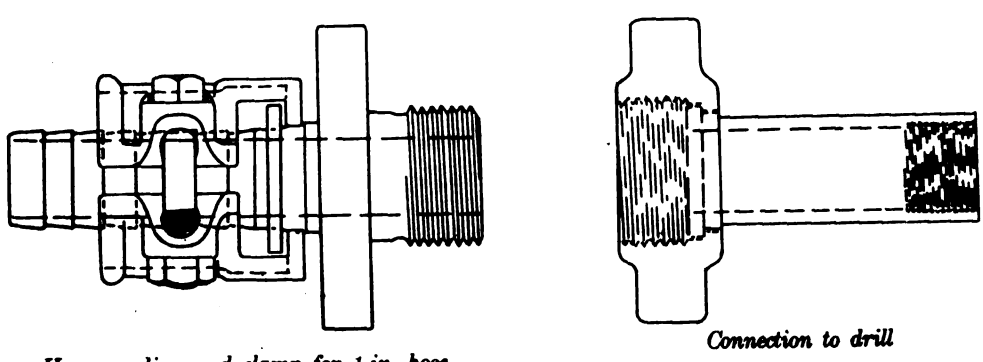


Figure 5b. – Valve and hose fittings for Leyner drills, using 1-in. air hose

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Raising

As far as possible raises are driven on a 45° slope, as it is found that the cost of driving is less on this angle.

Pilot raises in new ore bodies are usually 300 feet to 400 feet long and are driven up the dip at inclinations of 55 to 70°. Under these conditions they are made about 7 by 10 feet in cross section and timbered to provide a manway separate from the ore pass. Stulls of 10 by 10 timbers are spaced 5 feet from center to center on the footwall, and dividers are placed so as to leave a manway 3 feet 6 inches by 7 feet. The manway is provided with a heavy ladder, and a skidway is placed on this in a manner similar to that in the grizzly manways hereafter described. The manway is separated from the ore pass by 3 by 12 inch planks. The timbering is kept within about 25 feet of the face of the raise. The top of the manway is protected by a heavy bulkhead. When required, a ventilating fan is placed at the bottom of the raise, and air is carried to the face through 8-inch ventube.

After a connection is made the timbers are taken out of the raise and salvaged as far as possible. It is found that the large section used for these pilot raises is necessary for successful operation as an ore pass: A small raise chokes with wedged blocks of ore and is a source of trouble and expense.

Costs for timbered and inclined raises are not kept separate. (Large-size raises driven in ore are charged to stoping.) The average of all development raising is as follows per foot of advance:

Cost of development raising per foot of advance

	Labor	Supplies	Air	Total
Drilling	$2.214	$0.450	0.796	$3.460
Timbering	.147	.129	----	.276
Piping	.047	.047	----	.094
Explosives[1]	--	1.519	--	1.519
General	.131	.001	--	.132
Total	2.539	2.146	.796	5.481

1 50 per cent strength gelatin dynamite.

Compressed-Air Connections

A standardized system of hose connections has been developed which has reduced the number of parts and made machines and hoses readily interchangeable. These fittings are shown in Figure 5. Two sizes are required. Three-quarters-inch hose is used for stoping, blockholing, and raising. For drifting with Leyner-type machines it has been found that larger hoses are desirable and 1-inch fittings are provided for this purpose.

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Drill-Steel Sharpening and Drill Maintenance

Three classes of drill steel are used. Drifting machines use 1-1/4-inch hollow-round steel; jackhammers use 7/8-inch hollow-hexagon steel; and stoppers use 1-inch quarter-octagon drill steel. Double taper bits are used on each class of steel. Changes are 18 inches in length and 1/4 inch in diameter of bit. Soluble quenching oil is used at frequent intervals for keeping the shank ends of the drill steel of correct hardness to prevent breakage of the air drill pistons.

The following figures give the results of a 3 years' record of drill-steel breakage:

Machines	Drill steel	Ratio of steel sharpened to steel broken
Leyner	1-1/4 inch hollow round	10.86
Jackhammer	7/8 inch hollow hexagon	28.13
Stoper	1 inch quarter octagon	9.34

The cost of sharpening the three classes of drill steel per shift of air-drill operations is as follows:

	Cost per drill shift
Leyner type	$ 2.07
Jackhammer type	.42
Stoper type	.61

Waugh line oilers are used on all air-operated machines. A special man is used to fill these oilers on each shift. The average costs of machine drill maintenance for each class of drill is as follows per shift operated:

	Leyner type	Jackhammer	Stoper
Repair labor	$0.221	$0.028	$0.035
Repair supplies	1.774	.218	.164
Lubricants	.120	.094	.094
Total	2.115	.340	.293

As the ore and rock are both unusually hard, special efforts are made to keep all compressed air equipment in good mechanical condition so that the maximum return will be received from the operator's time.

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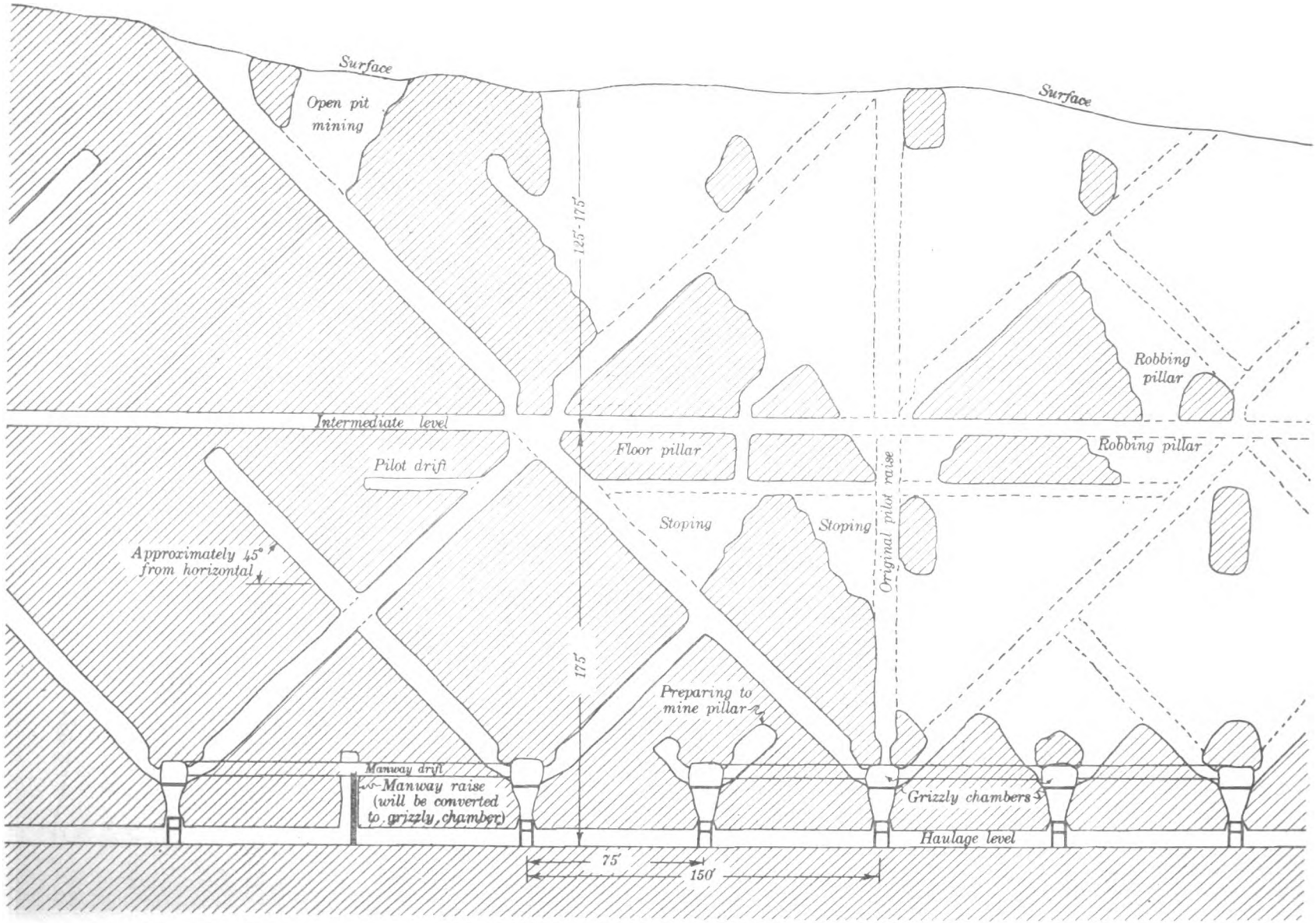

Figure 6. — Longitudinal section showing stoping method. Inclined to dip of ore body

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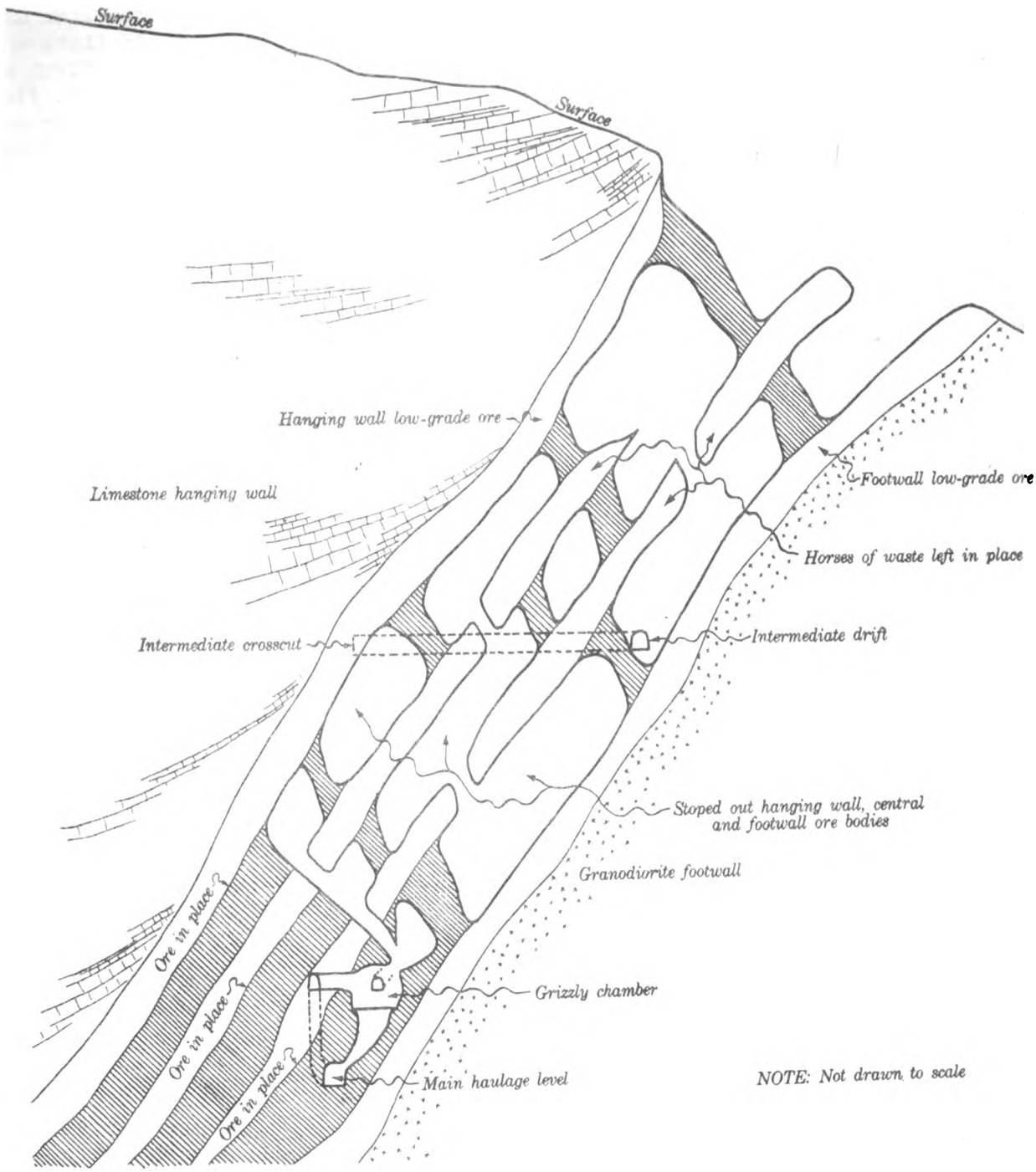

Figure 7. — *Idealized vertical section across the vein, showing ore body mined out above haulage level, excepting pillars*

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Mining Method

By driving an adit through the granodiorite to the contact ore body and then drifting along the ore, a vertical stoping distance of about 350 feet was made available on the west side of the valley. Figure 3 shows the position of this drift, known as the Continental main adit. It connects to the Continental shaft and affords good natural ventilation for the haulageways. One shaft has been put down below the haulage level, but the ore thus developed is not at present required, and stoping is carried on only above the adit level.

The method of stoping that has been developed for working these irregular bodies is classified as a "naturally supported open stope" with "irregular pillar arrangement". A number of special conditions are necessary to make this system applicable. The wall rock and the ore body must both be strong and capable of standing up over a considerable area. To justify the expense of cutting out the roof pillar the ore body should have a width of at least 25 feet.

Figure 6 shows an idealized longitudinal section inclined at about 40° from the vertical to illustrate the method of mining. Figure 7 shows a transverse section. The ore bodies are developed by chutes at 150-foot intervals along the main haulage level, with a manway raise half way between each alternate pair of chutes.

Chutes and Blasting Chambers

These chutes lead to grizzly chambers 25 feet above the level, where the large bowlders are bulldozed to pass a 16-inch opening. The grizzly bars are used in pairs, and are of 0.6 per cent carbon steel, 1 by 6 inches in section. These grizzly chambers are usually made in the ore. They are served by manway raises and drifts, the construction and design of which can be seen in Figure 8. The drifts are driven with a turn to protect the ladderway when blasting is being done. It is rarely necessary to timber the manway raises to the grizzly chambers, but they are provided with substantial ladders built with 3 by 4-inch sides and 2 by 4 by 28-inch treads spaced at 10-inch intervals center to center. These ladders are 20 inches wide inside and provided with 1 by 8 inch boards for a skidway for ease in raising and lowering drill steel and other supplies. From each side of the grizzly chamber, narrow short ore passes, 6 feet high and 5 feet wide, are driven 10 or 12 feet long to serve as a throat to stop the rush of ore onto the grizzly bars.

Stoping

The stopes are begun directly above this throat and driven upward, at a plus 38° inclination, in the ore both ways to connect to an intermediate level 150 feet above. In laying out future levels this distance will be increased to 175 feet in order to reduce the cost per ton in chutes and blockholing chambers. Small ore passes are continued in the ore above the intermediate level for 10 or 15 feet, and again stope-size inclines continue at plus 38° to the surface in the ore. The intermediate level is not continuous. It is stopped when the ore body pinches out or is interrupted by the intrustion of igneous masses.

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Underhand stoping can be started at the surface and the full width of the ore body taken in safety. The hanging-wall limestone is supported at irregular intervals by pillars formed by starting branch stopes from below and passing under the backs to be left. These workings give other places for undercutting with jackhammers after they connect to the surface or to the branches above. The pillars are trimmed and arched for safety toworkmen below.

In many cases, it has been necessary to use Leyner-type drifting machines mounted on columns for driving the pilot drifts under the roof pillars. Whenever the ore is not too hard a jackhammer machine is used supported by a hook from a bar of drill steel. The larger part of the production of the stope is mined by underhand stoping from the benches.

For cutting out the roof pillar and thus preserving the intermediate level, a small pilot drift is driven in ore from one inclined stope to the other, 15 feet below the level. This system was taken from the practice of the Burra-Burra mine[5]. Undercut mining can be started here as soon as this is completed and continued by benching the ore back from the raise along the pilot drift. The miners are at all times working in safely protected stopes with well-arched roof pillars to protect them from falling ore from above.

In like manner, branch stopes are begun above the intermediate levels at the tops of the narrow ore passes. In many instances hard siliceous material encountered in the development may be used for pillars in the subsequent stoping program, thus avoiding the necessity of leaving pillars of ore.

Hanging, central, and footwall bodies are mined through the same grizzly chambers by small branch raises, which pass through the horses of waste separating them. After a new body is reached, the stopes at plus 38° inclination are driven in a manner similar to that described above.

When stoping is nearly finished in one section of an ore body it is possible to trim pillars considerably and in many cases to take them out entirely. The walls are generally hard and often stand for months over long spans without support. Caving eventually occurs, and the limestone and horses of waste mix with the remains of what pillars of ore are left. This all falls to the grizzly chamber and is well mixed. In many cases it is possible to draw this mixed material and recover the magnetic ore in the cobbing plant. Not more than 10 per cent of the ore is lost in unrecoverable pillars.

This system lends itself well to selective mining, for it is possible to leave unprofitable or undesirable material. It is also possible to empty the chutes quickly and take out any waste that must be moved. Dikes and horses of silicates are continually being encountered that must be removed separately from the ore. The method also provides means of controlling the sulphur and silica in the mixture. It is often necessary to have the drillings analyzed for these elements before a round is blasted. The miners are changed from one part of the stope to another as required.

Ventilation is good in all the stopes after the first stope has made

5 - McNaughton, C. H. Mining Methods of the Tennessee Copper Co., Ducktown, Tenn.: Inf. Circ. 6149, Bureau of Mines.

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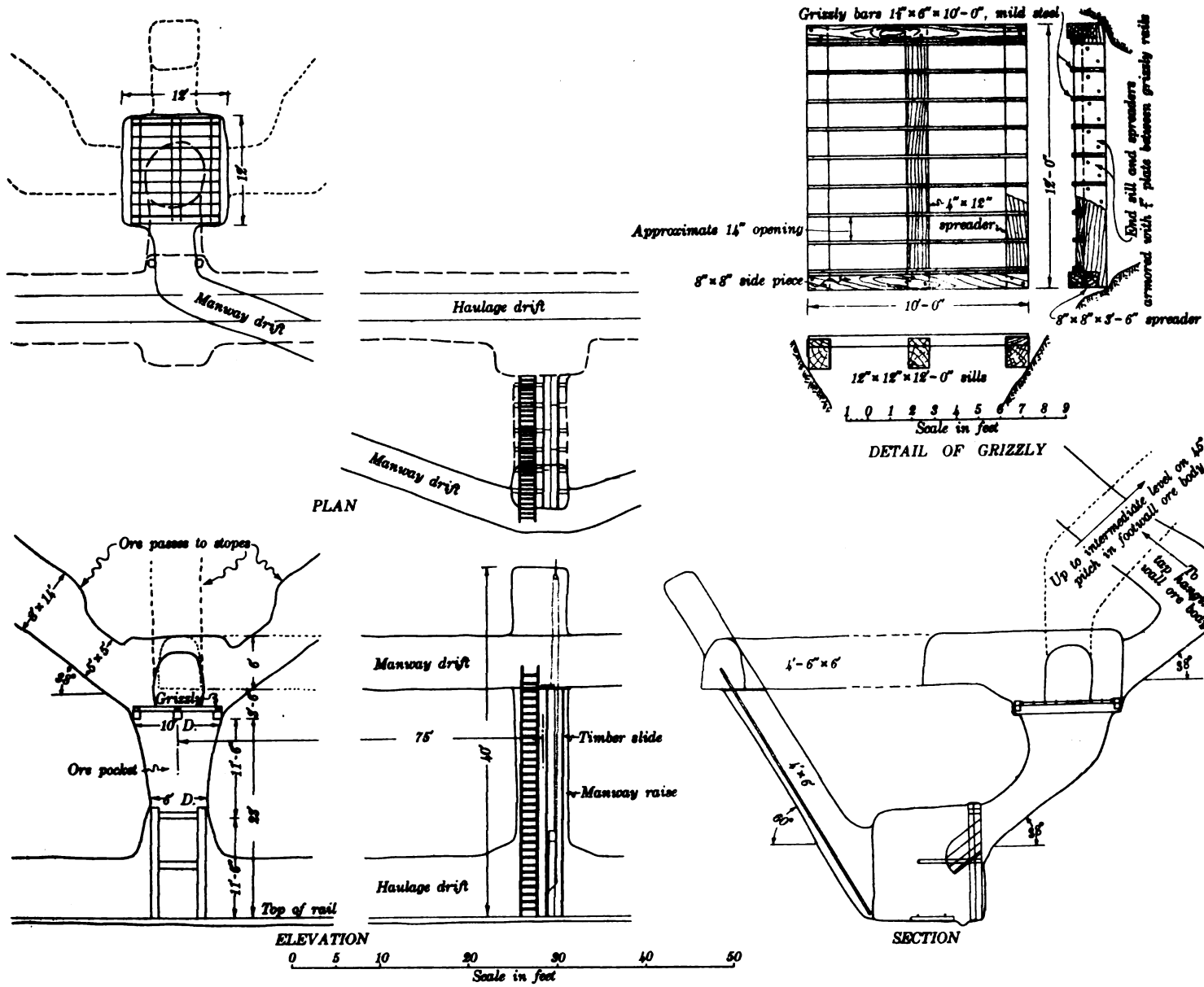

Figure 8.— Grizzly chamber and connecting drifts and raises

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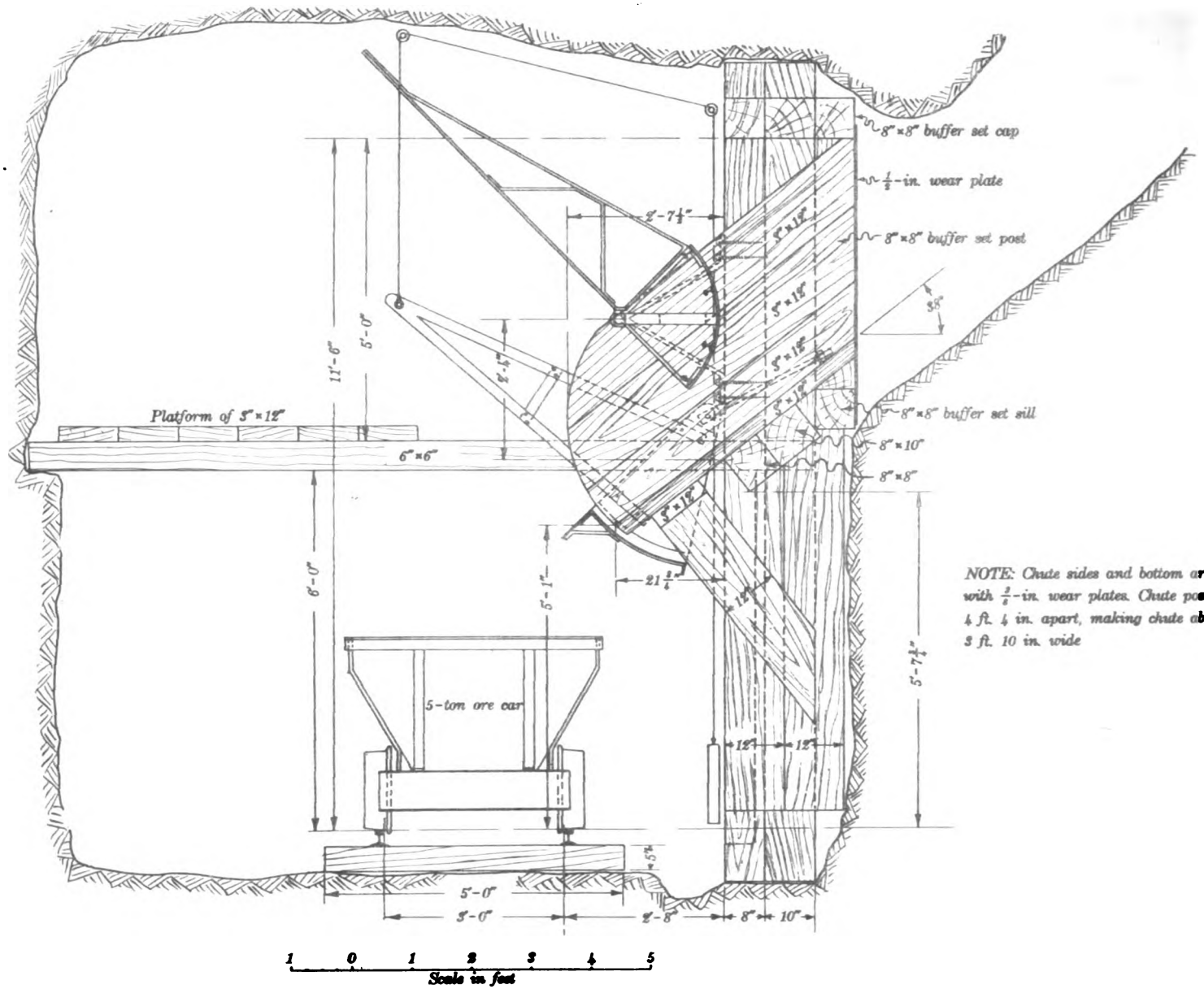

Figure 9.—Loading chute

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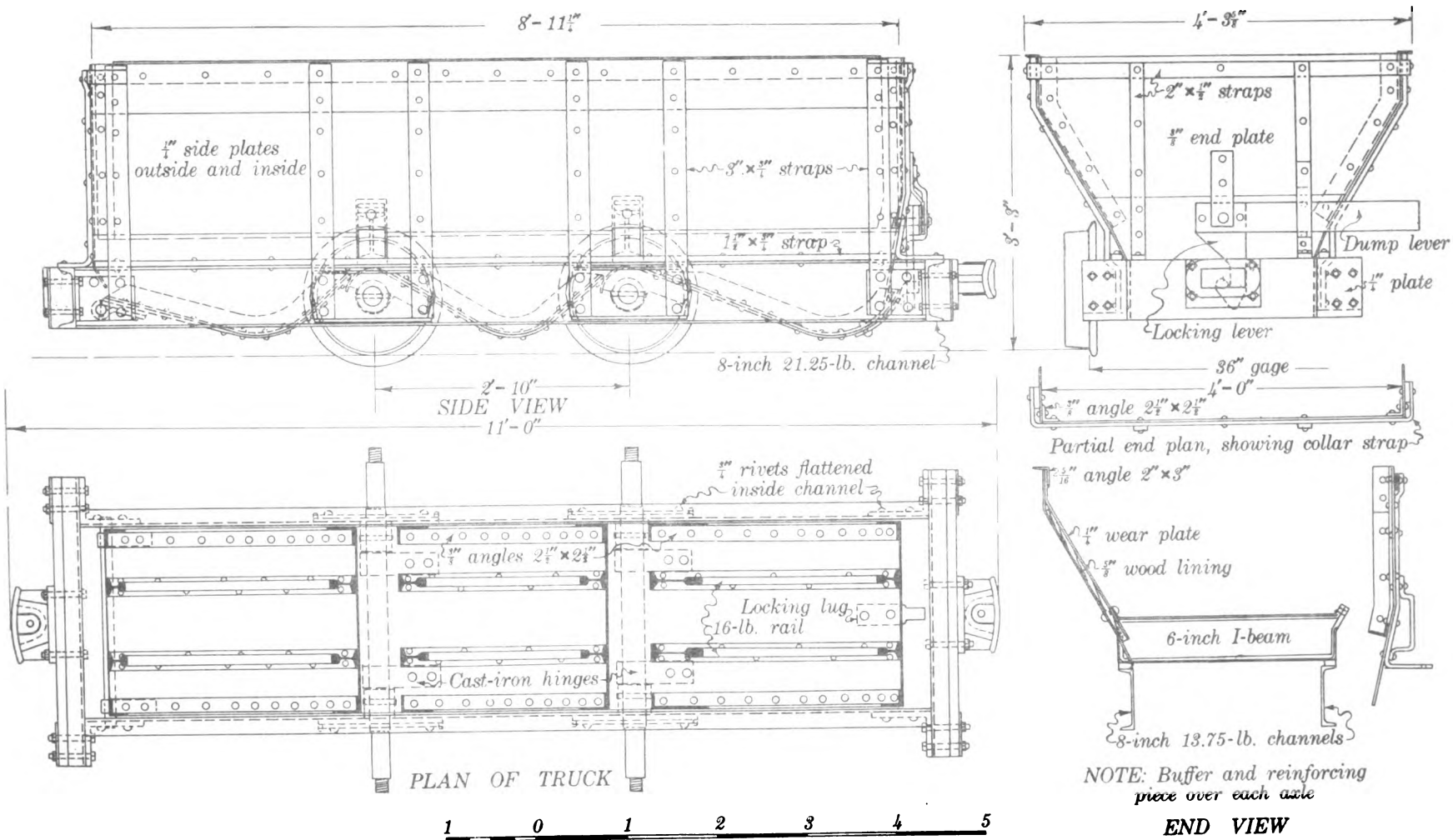

Figure 10.— Ore car, 65 cu. ft., 5-ton capacity

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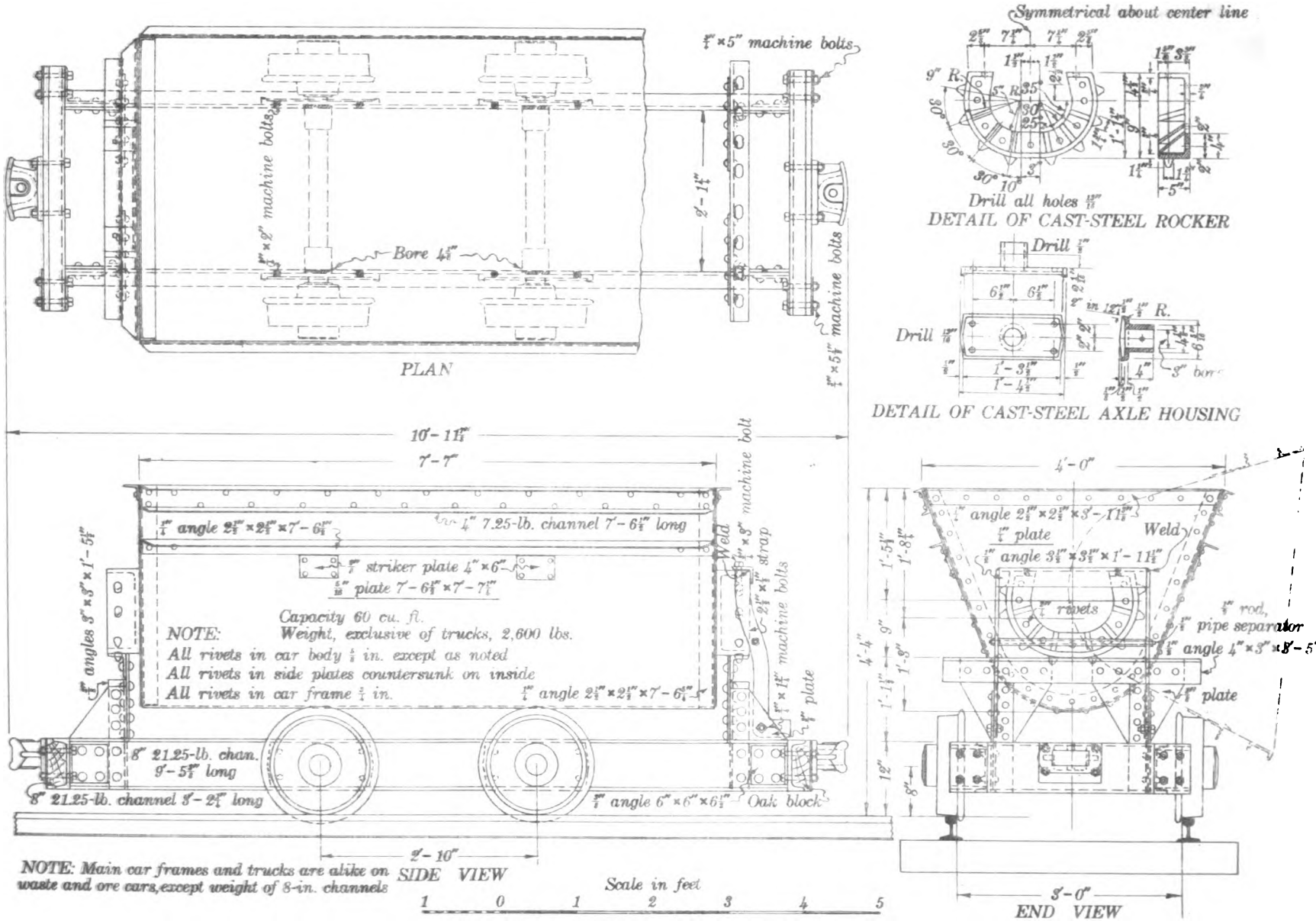
PLAN
SIDE VIEW
END VIEW
DETAIL OF CAST-STEEL ROCKER
DETAIL OF CAST-STEEL AXLE HOUSING
Symmetrical about center line
Drill all holes
Bore
Capacity 60 cu. ft.
Weight, exclusive of trucks, 2,600 lbs.
NOTE:
All rivets in car body in. except as noted
All rivets in side plates countersunk on inside
All rivets in car frame in.
NOTE: Main car frames and trucks are alike on waste and ore cars, except weight of 8-in. channels
Scale in feet
1 0 1 2 3 4 5

Figure 11. — Rocker-type waste car

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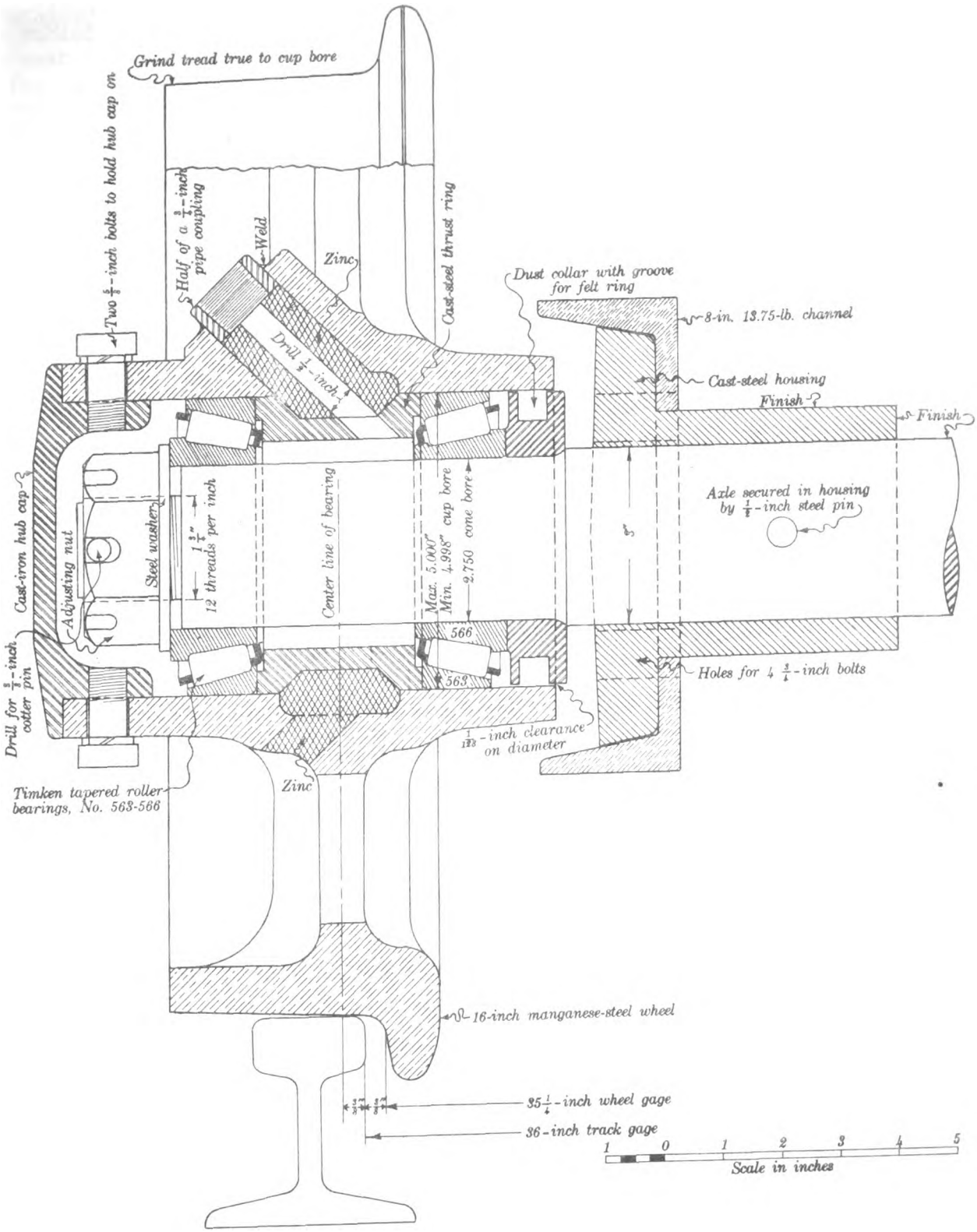

Figure 12. – Wheel and roller-bearing detail for ore and waste cars

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connection either to the intermediate level or to the surface. The stope faces are worked on only one shift, which gives time for the smoke to dissipate before the next shift. Compressed air for the first raises is supplied from the line on the main haulage level, through the manway raises and drifts, up through the narrow throat from the grizzly chamber, in 1-inch pipe, so supported that it suffers very little from falling or sliding rock. After connection to the intermediate level or surface, air and other supplies for stoping are taken into the stopes from above.

The ore broken by the day shift is passed through the grizzlies by the afternoon crew, who drill and blast on the grizzly bars as required. For this work, light jackhammers and 1-inch drill steel are used. Gelatine dynamite in 7/8-inch cartridge is used for blasting. The chute below the grizzly has sufficient capacity to hold a trainload of ore. The ore for the day shift hauling is drilled and blasted by the afternoon shift.

It might appear that this system of mining requires a large amount of raising. As the headings are large and in ore, the cost per ton of ore mined is not much higher than the cost for the ore broken by underhand stoping in the later development of the stope. It is an important feature of this system of mining that the use of shovels in the stopes has been almost eliminated. This is one reason for the low cost of operation.

As but little broken ore reserves are carried in the mine the amount of capital invested is less than in some other systems of mining. This advantage, and also the ability to do selective mining, make the system very well adapted to this class of ore.

No timber is used in the stopes except for bulkheads, to divert the run of ore from one place to another as a temporary measure, or to block the run of waste from worked-out stopes into ore passes.

With this system of mining, the amount of ore broken and delivered at the ore bin is 10.1 tons per man per shift employed underground.

Various contract and bonus systems have been tried for the payment of miners employed on stoping. These have increased the cost of supervision and have not reduced the cost of mining. At present all stoping labor is paid on a daily basis.

The costs of the operation are as follows:

Cost of stoping per long ton mined

	Labor	Supplies	Compressed air	Total
Drilling	$0.111	$0.023	$0.040	$0.174
Mucking	.001	--	--	.001
Timbering	.003	.003	--	.006
Piping	.004	.002	--	.006
Explosives[1]	--	.064	--	.064
General	.007	--	--	.007
Total	.126	.092	.040	.258
Total, per short ton	.112	.082	.036	.230

[1] 30 per cent strength gelatine dynamite.

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Cost of secondary breaking per long ton mined

	Labor	Supplies	Compressed air	Total
Blockholing	$0.046	$0.004	$0.006	$0.056
Grizzly maintenance	.002	.002	--	.004
Explosives[1]	--	.022	--	.022
General	.003	--	--	.003
Total	.051	.028	.006	.085
Total, per short ton	.046	.025	.005	.076

[1] 30 per cent strength gelatine dynamite.

Haulage

Experience in handling large tonnages of this magnetite ore, with an average weight of about 225 pounds per cubic foot, has taught important facts regarding the sturdiness of all equipment necessary for such service.

The standard chute set and the arrangement of overcut and undercut gates is shown in Figure 9. This chute was developed from the one used by the Fresnillo unit of the Mexican Corporation[6]. Since adopting it, accidents have been reduced to a minimum. The amount of spill from the gates is small. The strong construction results in low maintenance cost.

Griffith-type, bottom dump cars of heavy construction are used for ore hauling (fig.10). These cars have a volume of 60 cubic feet and hold 5 tons of broken ore. The low center of gravity and the simple construction make them very suitable for the service.

For waste haulage a rocker dump type of car is used (fig. 11). This car can be dumped from either side and has been found most suitable and economical for disposing of the waste on the dump.

Both ore and waste cars are equipped with the same kind of manganese steel wheels and tapered roller bearings (fig. 12). To save grinding expense on the inside of the wheels, steel thrust collars are made separately; zinc is cast around them to hold them in place. Fittings are provided for supplying grease under pressure. These wheels have been in service several years, have caused no expense for maintenance and show no appreciable wear.

At present 7-car trains are hauled by 5-ton storage-battery locomotives, each equipped with 80 A Edison cells. A battery-recharging station is located at the portal of the Union Hill adit, where the current of air from the mine is utilized to keep the temperature nearly constant. Convenient overhead trolleys and chain blocks are provided for handling the battery boxes.

Electric block-signal lights are installed along the haulageways to prevent accident and loss of time. Electric lights are also provided. Both signal and light wires are mounted with insulated metal expansion bolt brackets

6 - Baker, Thomas C., Fresnillo Glory-Hole Mining Practice, Details and Costs of the Mexican Corporation's Operation in Zacatecas: Eng. and Min. Jour.-Press, vol. 116, No. 22., p. 931.

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which hold them firm. Electric conduit is used to carry these wires past the loading chutes.

The cost of ore haulage per long ton-mile is as follows:

Hauling ore

	Labor	Supplies	Repairs	Power	Depreciation	Total
Chute operation	$0.026	--	$0.013	--	--	$0.039
Locomotive haulage	.066	$0.001	.029	$0.009	$0.012	.117
Track maintenance	.002	.006	--	--	--	.008
Car maintenance	.011	.005	.001	--	--	.017
General	.006	--	--	--	--	.006
Total per long ton mile	.111	.012	.043	.009	.012	.187
Total per short ton mile	.099	.011	.038	.008	.011	.167

ENGINEERING SYSTEM

The system used in the engineering department is based upon methods used by other companies in the Southwest but has been arranged to meet local conditions. As these methods have not been described previously in Bureau of Mines papers, they are now given in some detail.

Surveying

The first essential in a system of mine surveys is an accurate triangulation net covering the property. At Fierro, this net was started by constructing concrete monuments (fig. 13) at the places which were considered permanent and of easy access to the various mines. A base line was conveniently chosen and measured with a tape which had been standardized for temperature, pull, and sag by the United States Bureau of Standards. Its bearing was accurately established by solar observations and checked by observing Polaris. The elevation of the two base-line points was established by leveling from a United States Government bench mark about 1 mile north of Fierro.

The various triangles forming the net were then surveyed by repetition. After the preliminary corrections had been made to balance each triangle, the whole system was again balanced and corrected by the long method detailed in "Topographic Surveying"[7]. This last balancing was probably a refinement unnecessary for the small triangulation net at Fierro but was made for final accuracy.

A coordinate system was next established, large enough to include all company property in the northeast quadrant.

Surface surveys were made locating all open pits, shafts, tunnels, prospects, buildings, railroads, some topographic detail, and geological features. Solid permanent bench marks at important tunnel portals and elsewhere were established for reference. Stakes, 1 by 2 by 18 inch, were used for the traverse

[7] - Wilson, Topographic Surveying, Chapter 28.

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points and numbered consecutively by means of 1-inch-square galvanized iron tags. A record showing the location of these stations in numerical order is kept in the office. From the main traverse points all detail was located, each detail point having its number on the survey sheets. These points were computed on the field sheets and plotted on a scale of 1 inch to 40 feet on detail maps. Main traverse survey stations are all computed for latitude, departure, and elevation in standard computation books. The detail points are plotted by angles and distances, direct from the notes.

Underground surveys were then carried from surface traverses and bench marks to all mine workings. Underground surveys are numbered consecutively in order of survey; each separate working takes its own survey number and is thus indexed. Proper record of all surveys is made in regular computation books in the office, and proper indexing and filing keep all surveys and survey plugs coordinated. Each has its individuality without question. The plugs or stations are marked by 1/2 by 2 by 1/16 inch copper plates on which numbers are stamped consecutively and used in the order that stations are established, no matter what working is being surveyed. Hook-style spads are used for overhead plugs and are driven through the numbered plates.

In raise and stope surveys, where the plugs are temporary, the spad, without copper tags, is driven into the plug or timber and given a letter in the notes. Detail on stope surveys is taken by side shots from instrument points, computed directly on the sheets, and plotted by horizontal angle and distance. It has not been necessary at this property to make regular stope surveys for tonnage estimates. It is, however, very requisite, in stopes where the development or pilot raises are irregular and crooked, to have accurate lines given and maps made for connections above.

All surveys, when and where possible, are tied together as a check on the accuracy of the work.

Field notes are kept on loose-leaf cards (5 by 8 inch), carried in a metal-spring back book. These cards are filed and indexed in the office and are kept in the files, except when actually in use. All new plugs or points are recorded on the proper tag index sheets. The computation book number and page number are marked on the corresponding field sheets in order that each separate computation may be found easily for checking purposes. Each survey has its separate page or group of pages in the computation books. A record sheet of computation, indexing, filing, and checking is kept on each survey number. The engineer usually computes his own notes, which are later checked by the helper. Any mistakes are rechecked by the engineer and from the checked computations a simple record card (5 by 8 inch) is filled out, showing only the stations, bearing, horizontal distance, latitude, departure, and elevation of each survey station, with references and remarks on how and where to find the original notes. These record sheets take the same survey numbers as the field sheets, are filed in order, and carry sufficient data for plotting on the maps.

Mapping

A guide map was made on a scale of 1 inch to 500 feet covering the entire property, upon which are plotted only the important underground levels,

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surface claims, government sub-division corners, the triangulation net, and the system of coordinates. This sheet is divided into parallelograms, 1,100 feet in a north-south direction, numbered consecutively from south to north; and 1,500 feet in an east-west direction, lettered consecutively from west to east.

On the guide map also appear the exact position and size of the large table maps, from which the above-mentioned tracings are made. The table maps are made on Duplex cloth-mounted detail paper on a scale of 1 inch to 40 feet and are 52 inches wide and from 15 to 18 feet in length. They are composite working maps; and on them appear all levels, main and intermediate, and surface details. They are brought up to date at the first of each month; and the position of all raises, winzes, shafts, diamond-drill holes, and prospect holes is plotted. These maps show full detail of all mine workings but not analyses or geology, which information is placed on tracings.

These tracings are 30 by 40 inches, and made separately for the surface and each level of the underground workings. Each tracing is given a serial number and also its coordinate letter and number as shown on the guide map. Thus:

HANOVER BESSEMER IRON & COPPER CO.

Fierro, New Mexico

UNION HILL MINE -- 300 LEVEL

Assays and Geology

Scale - 1 in. = 40 ft. Date 3-7-25

Sheet No. 26-G-10 By F. B. H.

File No. 30 - B

The number "26" means that it was the 26th tracing to be made from the large mounted maps. The coordinate letter "G" and number "10" correspond to its position on the guide map. The mine and level represented are given in the title, and the File No. "30-B" is the filing card reference and drawer letter in the map cabinet.

All tracings of mine maps are of this size and are filed together. The sheets were purchased already printed and coordinated, and fit exactly over each other.

Vertical sections, normal to the general strike of the contact, and at 100-foot intervals along a guide line drawn on the large table maps, are drawn on tracing cloth. These sections are kept up-to-date to show all workings, assays, and geological data.

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White prints are made from the tracings, and the ore bodies are outlined and colored on these prints. Similar sets are made from the plan tracings and colored. These prints are of great help in calculating ore reserves and in directing development work.

Special stope maps are made on a scale of 1 inch to 20 feet for the use of the mining department. On this larger scale, the plotting of detail can be done to better advantage. Tracings of these stope maps, which are brought up to date from time to time, are carried by the mine superintendent for reference underground. Cloth stands the hard wear and folding better than prints.

The original large table maps and stope maps are rolled and filed in pigeonholes in the vault properly designated for them. All other maps are made in one of four standard sizes and filed flat in the drawers of the filing cabinet. The drawers of the cabinet are lettered. Each map is numbered consecutively regardless of the size; but it also carries a letter to designate the drawer in which it belongs. The following table will make the filing arrangement more clear:

	30 by 40 inches	23 by 38 inches	18 by 24 inches	8-1/2 by 11-1/2 inches
Original	A	D	G	J
Tracing	B	E	H	K
Print	C	F	I	L

In this way, the originals, tracings, and prints are kept separated in the cabinet. Foreign maps are trimmed or folded and filed in the same manner. One drawer is used exclusively for the 30 by 40 inch mine tracings so that they may be found quickly and kept separate from all other classes of tracings. To index all maps and keep the numbers in order an index book is used in which all drawings and maps are listed as received. A card index is also maintained in which each drawing is cross-indexed under all possible headings for easy reference.

MAGNETIC CONCENTRATION

The ore, as it is brought from the mine, is dumped through the bottom doors of the ore cars into the hopper of a No. 9 D gyratory crusher. This reduces the size to pass a 5-inch opening. From the discharge, the ore is carried to the storage bin by a belt conveyor. The arrangement of the crushing and cobbing equipment is shown on the flow sheet in Figure 14.

The operation is conducted dry. As the dust is heavy and abrasive, special means are provided to protect the electrical equipment. Sealed sleeve motors are used throughout. All other bearings are provided with fittings for the use of grease under pressure. The larger motors are installed in dustproof houses, using steel housings around the pulleys and belts. All of the starting switches are located inside of a dust proof room and arranged in order, so that the equipment can be started in the proper sequence.

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For the magnetic separation, three belt-type concentrators are used on the coarser sizes, and an agitating drum-type machine is used for the fine size. The comparative results obtained by the different machines is shown in the following table of a typical day's operation on dry material.

Size	Amperes	Heads		Concentrates		Tails		Recovery, per cent
		Tons	Per cent Fe	Tons	Per cent Fe	Tons	Per cent Fe	
Plus 1.5 inch	4.0	204	42.1	168	48.0	36	14.4	94.0
Minus 1.5 inch plus 0.75 inch	3.5	218	44.7	181	50.8	37	15.1	94.3
Minus 0.75 inch plus 0.17 inch	3.0	195	42.3	148	50.9	47	15.1	91.4
Minus 0.17 inch	5.0	265	38.4	158	53.2	107	16.5	82.6
Combined		882	41.7	655	50.7	227	15.7	90.3

At times the presence of a small amount of moisture in the fine ore reduces the per cent of recovery and the percentage of iron in the concentrates of the fine size. Some of the ore mined is uniformly low in iron percentage and cannot be much improved by concentration at the size that grinding is now done. By grinding to minus 60 mesh, the iron and impurities can be separated, and concentrates high in iron can be obtained by magnetic means.

The field strength is controlled by varying the amperes in the circuit while the number of turns on the poles is constant. This adjustment is very sensitive. A small change in the amperes makes a considerable change in the recovery obtained and in the iron percentage of the products.

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Detail of cost in units of labor, power, and supplies, year 1929[1]

Labor

Long tons mined per man-shift underground.....	10.12	(11.33)
Long tons concentrates shipped per man-shift (all labor surface and underground).....	5.11	(5.72)

	Pounds dynamite	Feet fuse	Number caps
Supplies			
Explosives			
Stoping per long ton mined...	0.355 (0.317)	0.89 (0.79)	0.126 (0.113)
Secondary breaking per long ton mined.....	.096 (.086)	.46 (.41)	.151 (.135)
Drifting per foot.....	9.92	26.17	4.20
Raising per foot.....	7.30	21.80	2.74
All purposes per long ton mined.....	.580 (.518)	1.71 (1.53)	.329 (.294)
	Kilowatt hours		
Electric energy			
Compressed air per long ton ore mined.....	2.91	(2.60)	
All purposes per long ton concentrates shipped.....	6.91	(6.18)	

1 - Note: Figures in parentheses have been reduced to a short-ton basis.

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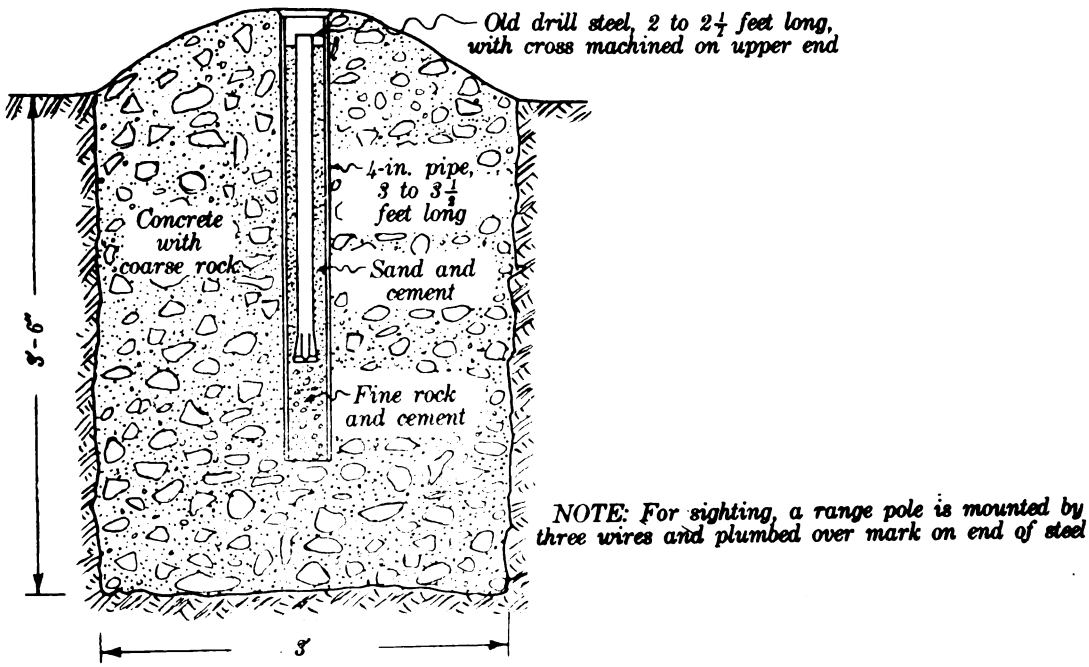
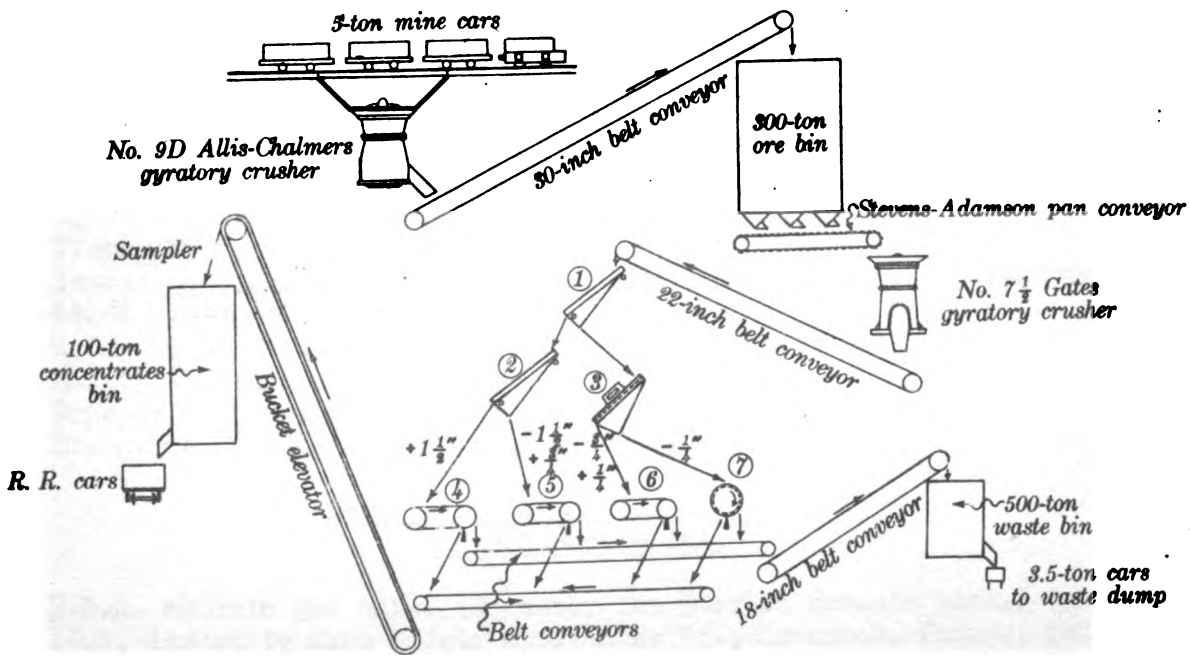

Old drill steel, 2 to 2½ feet long, with cross machined on upper end
4-in. pipe, 3 to 3½ feet long
Concrete with coarse rock
Sand and cement
Fine rock and cement
3'-6"
3'
NOTE: For sighting, a range pole is mounted by three wires and plumbed over mark on end of steel

Figure 13. – Triangulation monument. Not drawn to scale



① 36 by 48 inch ratchet grizzly, ¾-inch openings
② 36 by 48 inch ratchet grizzly, 1½-inch openings
③ Traylor "Supreme" electric vibrator screen, ¼-inch openings
④ Ding's magnetic cobbing machine, belt type, using 4 amperes
⑤ Ding's magnetic cobbing machine, belt type, using 3½ amperes
⑥ Ding's magnetic cobbing machine, belt type, using 3 amperes
⑦ Ding's magnetic cobbing machine, agitating drum type, using 5 amperes

Figure 14. – Flow sheet of cobbing plant

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